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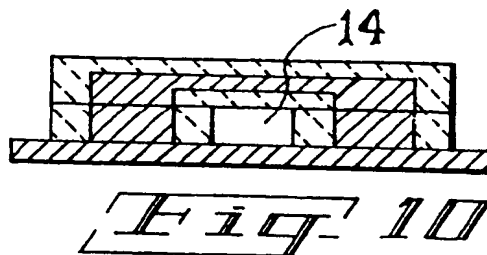
### Remarks:

A request for correction in the description and the addition of a no."1" in figure 1 has been filed pursuant to Rule 88 EPC. A decision on the request will be taken during the proceedings before the Examining Division (Guidelines for Examination in the EPO, A-V, 3.).

### (54) Method of forming air bridges

(57) Disclosed is a method for making an air bridge in an electronic device. This method uses amorphous silicon carbide to protect electrical conductors in the de-

vice during formation of the bridge. The silicon carbide also provides hermetic and physical protection to the device after formation.



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## Description

The present invention relates to a method of forming air bridges on electronic devices. The method uses amorphous silicon carbide to protect the conductors on the device during and after the air bridge formation.

The electronics industry continues to strive to decrease the size of devices. One of the difficulties in the process of miniaturization is maintaining a sufficient dielectric between conductors to prevent device failure.

To solve this problem, the industry has investigated a wide variety of low dielectric constant materials. These materials have shown to provide dielectric constants of 2 and above. Unfortunately, many of these materials are difficult to process and their chemical and physical properties can be incompatible with the devices.

One of the best dielectrics available is air. Various investigators have attempted to capitalize on this by leaving voids between adjacent conductors. These voids are often called "air bridges". For instance, US Patent 5,324,683 describes the formation of an air bridge in an integrated circuit by removing all or a portion of a dielectric layer between conductors. The methods, materials and final product described therein, however, are different from those of the present invention.

We have unexpectedly discovered a method for forming an air bridge which uses the properties of silicon carbide in its formation and which has the unexpected advantage of being more durable after formation.

The present invention relates to a method for forming an air bridge on an electronic device. The method comprises first forming 2 separate conductors on an electronic device. These conductors have edges which are laterally adjacent to each other and the conductors are separated by a void. Next, amorphous silicon carbide coatings are formed on the edges of the conductors which are laterally adjacent to each other such that the size of the void is decreased by the thickness of the coatings, while still leaving a void therebetween. Next, a sacrificial material is formed in the void between the laterally adjacent amorphous silicon carbide coated surfaces on the conductors. An amorphous silicon carbide coating is then formed on the sacrificial material. This coating is formed so it contacts the amorphous silicon carbide coatings on the edges of the conductors and, thereby, encapsulates the sacrificial material in amorphous silicon carbide. The conductive bridge is then formed to electrically connect the conductors. This bridge is formed on the 2 conductors and the amorphous silicon carbide coating covering the sacrificial material. An amorphous silicon carbide coating is then deposited to cover the conductive bridge. Finally, the sacrificial material is etched to leave an air bridge between the silicon carbide on the conductors.

Figure 1 is an electronic device having conductors thereon.

Figure 2 is the electronic device of Figure 1 coated with silicon carbide.

Figure 3 is the electronic device of Figure 2 wherein the silicon carbide is etched so the edges of the conductors laterally adjacent to each other are coated with silicon carbide.

Figure 4 is the electronic device of Figure 3 coated with a sacrificial material.

Figure 5 is the electronic device of Figure 4 wherein the sacrificial material is patterned to fill the void between the coated conductors.

Figure 6 is the electronic device of Figure 5 coated with silicon carbide.

Figure 7 is the electronic device of Figure 6 wherein the silicon carbide is patterned.

Figure 8 is the electronic device of Figure 7 wherein a conductive bridge is formed.

Figure 9 is the electronic device of Figure 8 coated with silicon carbide.

Figure 10 is the electronic device of Figure 9 wherein the sacrificial material is removed.

The present invention is based on our discovery that the properties of amorphous silicon carbide (or "silicon carbide") can be used in the process of forming air bridges. This process provides a practical means for producing air bridges and, thereby, solves one of the problems involved in miniaturization. Additionally, the resultant air bridge is more durable than those known in the art since the conductors are protected and sealed by the amorphous silicon carbide coatings.

The first step in the present invention involves forming 2 separate electrical conductors ("conductors") on an electronic device. These conductors can be formed at any level within the device. An exemplary electronic device is shown in Figure 1 as (1) and the conductors are shown as (2).

The electronic device used herein is not critical and nearly any which are known in the art, and/or produced commercially, are useful herein. These include silicon based devices, gallium arsenide based devices, focal plane arrays, opto-electronic devices, photovoltaic cells and optical devices.

Also, the material used in making the conductor herein is not critical and nearly any which is known in the art and/or produced commercially is useful herein. These include, for example, metals such as aluminum, copper, gold, silver and platinum; a silicide; polysilicon; amorphous silicon; a conductive organic material or a conductive inorganic material.

Methods for depositing these conductors are also known in the art. The specific method utilized is again not critical. Examples of such processes include various physical vapor deposition (PVD) techniques such as sputtering and electron beam evaporation or various liquid deposition techniques.

As shown in Figure 1, the conductors are formed on the device such that they are separated by void area (3). In addition, the conductors have edges (4) which are laterally adjacent to each other on the surface of the device.

The next step in the invention involves forming amorphous silicon carbide coatings on the edges of the conductors (4) which are laterally adjacent to each other such that the size of the void (3) is decreased by the thickness of the coatings (7). These coatings are shown in Figure 3 as (6).

Generally, these coatings are formed on the conductors by a process which comprises depositing amorphous silicon carbide on the entire top surface of the device as shown by (5) in Figure 2. This amorphous silicon carbide is then patterned and etched to leave coatings (6) on the conductor. Other equivalent means such as patterned deposition, however, are also feasible for use in the invention.

The method of applying the silicon carbide is not critical to the invention and many are known in the art. Examples of applicable methods include a variety of chemical vapor deposition techniques such as conventional CVD, photochemical vapor deposition, plasma enhanced chemical vapor deposition (PECVD), electron cyclotron resonance (ECR) or jet vapor deposition and a variety of physical vapor deposition techniques such as sputtering and electron beam evaporation. These processes involve either the addition of energy (in the form of heat, plasma, etc.) to a vaporized species to cause the desired reaction or the focusing of energy on a solid sample of the material to cause its deposition.

In conventional chemical vapor deposition, the coating is deposited by passing a stream of the desired precursor gases over a heated substrate. When the precursor gases contact the hot surface, they react and deposit the coating. Substrate temperatures in the range of 100-1000°C. are sufficient to form these coatings in several minutes to several hours, depending on the precursors and the thickness of the coating desired. If desired, reactive metals can be used in such a process to facilitate deposition.

In PECVD, the desired precursor gases are reacted by passing them through a plasma field. The reactive species thereby formed are then focused at the substrate where they readily adhere. Generally, the advantage of this process over CVD is that lower substrate temperature can be used. For instance, substrate temperatures of 50°C. to 600°C. are functional.

The plasma used in such processes can comprise energy derived from a variety of sources such as electric discharges, electromagnetic fields in the radio-frequency or microwave range, lasers or particle beams. Generally preferred in most plasma deposition processes is the use of radio frequency (10 kHz - 10<sup>2</sup> MHz) or microwave (0.1-10 GHz) energy at moderate power densities (0.1-5 watts/cm<sup>2</sup>). The specific frequency, power and pressure, however, are generally tailored to the precursor gases and the equipment used.

The precursor gases are also not critical to the invention. Examples of suitable precursor gases include (1) mixtures of silane or a halosilane, such as trichlorosilane, in the presence of an alkane of one to six car-

bon atoms such as methane, ethane or propane; (2) an alkylsilane such as methylsilane, dimethylsilane, trimethylsilane and hexamethyldisilane; or (3) a silacyclobutane or disilacyclobutane as described in US Patent 5,011,706. Especially preferred in the present invention is the plasma enhanced chemical vapor deposition of trimethylsilane.

Likewise, the method of etching is not critical and nearly any process known in the art will function herein. These include, for example, dry etching (eg., with plasma), wet etching (e.g., with aqueous hydrofluoric acid) and/or laser ablation.

Next, sacrificial material is deposited in the void between the adjacent amorphous silicon carbide coated surfaces on the conductors. This is shown in Figure 5 as material (9). This material is also generally formed by a process which comprises depositing the sacrificial material on the entire top surface of the device as shown by (8) in Figure 4. This sacrificial material is then patterned and etched to leave material (9) in the void. Other equivalent means such as patterned deposition, however, are also contemplated for the invention.

The sacrificial material used herein is not critical as long as it can be etched without etching or damaging the electronic device, the conductors or the silicon carbide. These materials include, for example, oxides, nitrides, fluorinated materials, organic materials and polymeric materials. Specific examples include silicon dioxide, silicon nitride, titanium nitride, borosilicate glass and polyimide. Preferred is silica derived from hydrogen silsesquioxane resin which is applied by a process such as that described in US Patent 4,756,977.

The sacrificial materials are applied by techniques known in the art for the material chosen. Such techniques can include, for example, spin-on processes, chemical vapor deposition, plasma enhanced chemical vapor deposition and sputtering.

Again, if the material is to be patterned and etched, it is performed by techniques known in the art. As before, they include dry etching, wet etching and/or laser ablation.

An amorphous silicon carbide coating is then deposited on the sacrificial material. This coating is deposited so that it contacts the amorphous silicon carbide coatings on the edges of the conductors and, thereby, encapsulates the sacrificial material. This is shown in Figure 7 wherein silicon carbide layer (11) is deposited on sacrificial material (9) and contacts the coatings (6) on the conductors.

Generally, these coatings are formed by a process which comprises depositing amorphous silicon carbide on the entire top surface of the device as shown by (11) in Figure 6. This amorphous silicon carbide is then patterned and etched to leave coatings (10) on the sacrificial material. Other equivalent means such as patterned deposition, however, are also contemplated. The materials and methods for depositing and etching the coating on the sacrificial material are not critical and many are

known in the art. Generally, these are the same as those described above for forming the previous silicon carbide coating.

Next, a conductive bridge which electrically connects the conductors is formed. As shown in Figure 8, this bridge (12) is formed on the 2 conductors (2) and the amorphous silicon carbide coating covering the sacrificial material (10). The materials and methods for forming this bridge are known in the art and are generally the same as those described above used in forming the conductors.

Amorphous silicon carbide is then deposited to coat the conductive bridge. This is shown in Figure 9 as coating (13). This, again, can be done by selective deposition or by deposition and etching. The materials and methods for depositing and etching the coating on the conductive bridge are not critical and many are known in the art. Generally, these are the same as those described above for forming the previous silicon carbide coating.

Finally, the sacrificial material is etched to leave the air bridge. This is shown in Figure 10 as void (14). The method of etching, again, is not critical and any known in the art can be used as long as the etching is limited to the sacrificial material. These include, for example, dry etching, wet etching and/or laser ablation.

The resultant device has the desired air bridge as shown in Figure 10. In addition, however, the air bridge of the present invention has silicon carbide protecting the conductors. This provides both a hermetic barrier to inhibit degradation caused by corrosion as well as a physical barrier to prevent shorting which may result if the bridge is physically altered.

## Claims

1. A method for forming air bridges on an electronic device comprising:

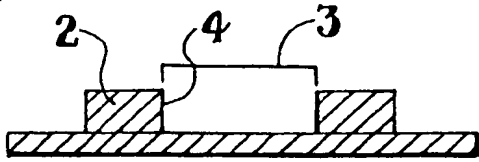
forming a first conductor and a separate second conductor on an electronic device (1), said conductors (2) having edges (4) which are laterally adjacent to each other and separated by a void (3);

forming a first amorphous silicon carbide coating (6) on the edges of the conductors which are laterally adjacent to each other such that a void remains but the size of the void is decreased by the thickness of the coatings (7); depositing a sacrificial material (9) in the void between the laterally adjacent amorphous silicon carbide coated edges of the conductors; depositing a second amorphous silicon carbide coating (11) to cover the sacrificial material, said coating contacting the amorphous silicon carbide coatings on the edges of the conductors to encapsulate the sacrificial material;

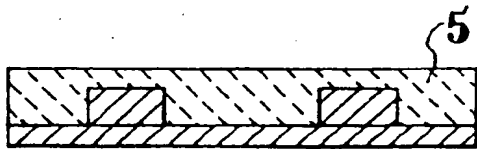
depositing a conductive bridge (12) which electrically connects the first and second conductors, said bridge being deposited on the first and second conductors and the amorphous silicon carbide coating covering the sacrificial material;

depositing a third amorphous silicon carbide coating (13) to cover the conductive bridge; and etching the sacrificial material to leave the air bridge.

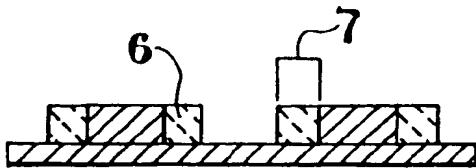
2. The method of claim 1 wherein the electronic device (1) is a silicon based device, gallium arsenide based device, focal plane array, opto-electronic device, photovoltaic cell or an optical device.
3. The method of claim 1 or 2, wherein each conductor (2) is made from a material selected from aluminum, copper, gold, silver, platinum, a silicide, polysilicon, amorphous silicon, a conductive organic material and a conductive inorganic material.
4. The method of any of claims 1 to 3, wherein each conductor (2) is deposited by physical vapor deposition or liquid deposition.
5. The method of any of claims 1 to 4, wherein the first amorphous silicon carbide coating (6) is formed by the plasma enhanced chemical vapor deposition of trimethylsilane.
6. The method of any of claims 1 to 5, wherein the sacrificial material (9) is silica derived from hydrogen silsesquioxane resin.
7. The method of any of claims 1 to 6, wherein the second amorphous silicon carbide coating (11) is formed by the plasma enhanced chemical vapor deposition of trimethylsilane.
8. The method of any of claims 1 to 7, wherein the conductive bridge (12) is made from aluminum, copper, gold, silver, platinum, a silicide, polysilicon, amorphous silicon, a conductive organic material or a conductive inorganic material.
9. The method of claim 8 wherein the conductive bridge (12) is deposited by physical vapor deposition or liquid deposition.
10. The method of any of claims 1 to 9, wherein the third amorphous silicon carbide coating (13) is formed by the plasma enhanced chemical vapor deposition of trimethylsilane.
11. The method of any of claims 1 to 10, wherein the sacrificial material is etched by dry etching, wet etching or laser ablation.



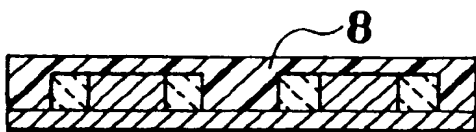
*Fig. 1*



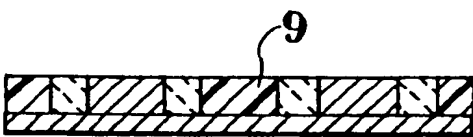
*Fig. 2*



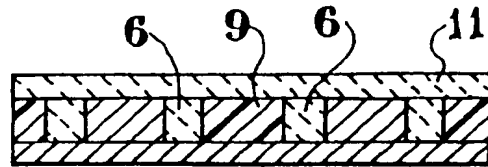
*Fig. 3*



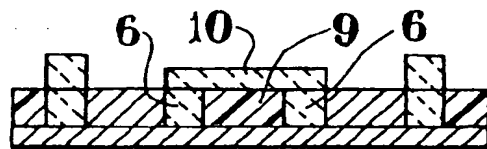
*Fig. 4*



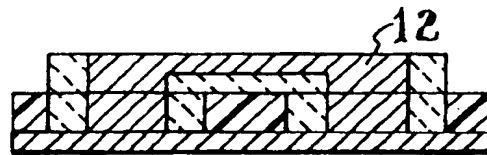
*Fig. 5*



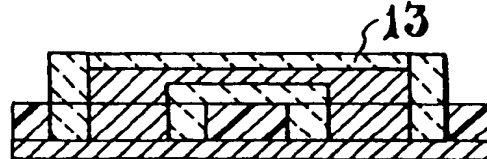
*Fig. 6*



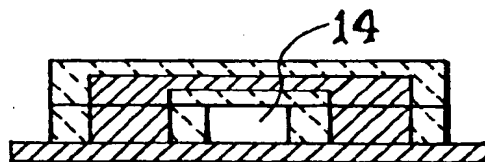
*Fig. 7*



*Fig. 8*



*Fig. 9*



*Fig. 10*



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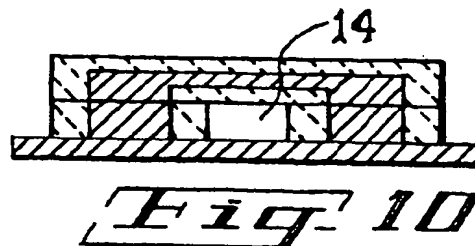
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**(54) Method of forming air bridges**

(57) Disclosed is a method for making an air bridge (14) in an electronic device. This method uses amorphous silicon carbide (6, 11, 13) to protect electrical con-

ductors (2) in the device during formation of the bridge (14). The silicon carbide (13) also provides hermetic and physical protection to the device after formation.



**Fig. 10**

**EP 0 771 026 A3**



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# EUROPEAN SEARCH REPORT

Application Number  
EP 96 30 7505

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 501 407 A (TOKYO SHIBAURA ELECTRIC CO) * the whole document *	1	H01L21/768 H01L23/482 H01L23/532 H01L23/538
A	PATENT ABSTRACTS OF JAPAN vol. 014, no. 022 (E-874), 17 January 1990 & JP 01 262646 A (SHARP CORP), 19 October 1989, * abstract *	1	
A	PATENT ABSTRACTS OF JAPAN vol. 014, no. 448 (E-0983), 26 September 1990 & JP 02 177550 A (TOSHIBA CORP), 10 July 1990, * abstract *	1,2	
A	US 5 148 260 A (INOUE TOMOTOSHI ET AL) * the whole document *		
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H01L
The present search report has been drawn up for all claims			
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>30 March 1998</b>	Examiner <b>Königstein, C</b>
<p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons &amp; : member of the same patent family, corresponding document</p>			

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